ERCB/AGS Open File Report 2011-03

Measured Outcrop Sections T2-R6W4-01 and T2-R6W4-02 of the Foremost and Oldman Formations (Belly River Group), Pinhorn Provincial Grazing Reserve, Milk River Valley, Southeastern Alberta (NTS 72E/02)

Energy Resources Conservation Board

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B. Hathway, C.J. Banks, D.C. Hay and G.J. Prior

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Alberta Geological Survey
4th Floor, Twin Atria Building
4999 – 98th Avenue
Edmonton, AB T6B 2X3
Canada

Tel: 780.422.1927
Fax: 780.422.1918
E-mail: AGS-Info@ercb.ca
Website: www.ags.gov.ab.ca

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Acknowledgments

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Abstract

In this report, we present data on two measured outcrop sections (T2-R6W4-01 and T2-R6W4-02) of the Belly River Group measured on the Pinhorn Provincial Grazing Reserve on the northern side of the Milk River valley in southeastern Alberta. Both measured sections include the upper part of the Foremost Formation and a large part of the overlying Oldman Formation. The lowermost part of the exposed Foremost Formation interval consists mainly of dark grey-brown silty mudstone with thin sandstone and siltstone interbeds. Rare, thicker sandstone beds and isolated sand-filled gutter casts commonly show hummocky cross-stratification. The lower mudstone-dominated interval is overlain by a thick sandstone unit showing swaley cross-stratification. A coal seam at the top of the thick sandstone unit marks the base of the Taber coal zone, which forms the upper part of the exposed Foremost Formation interval. The Taber coal zone consists mainly of mudstone and siltstone (commonly carbonaceous); a number of coal seams (up to 1.2 m thick); relatively thin (up to 1.5 m thick), commonly ripple crosslaminated sandstone units; and in the lower part, a thick sandstone unit showing swaley cross-stratification, horizontal planar stratification and cross-stratification.

The Oldman Formation is distinctly paler in colour than the underlying Foremost Formation. It consists mainly of muddy siltstone with subordinate fine- to very fine grained, fining-upward sandstone units up to 4 m thick, which commonly show trough cross-stratification and/or ripple crosslamination. Sandstone-dominated intervals in the upper part of each measured section represent the Comrey sandstone.

In both measured sections, outcrop gamma-ray counts show an abrupt shift to higher values at the top of the thick sandstone unit in the lower part of the Taber coal zone, which is generally sustained up through the overlying Oldman Formation. The marked difference in gamma-ray counts for units with similar lithology and grain size above and below this shift suggests that a compositional difference may be the controlling factor.

The report includes graphic logs of the measured sections, with outcrop gamma-ray curves; detailed description of the sections (avoiding lithofacies interpretation but detailing stratigraphic context where appropriate) with selected photos; and the results of biostratigraphic work on a sample from the lower part of measured section T2-R6W4-02.

1 Introduction

In this report, we present data on two outcrop sections (T2-R6W4-01 and T2-R6W4-02) of the Belly River Group on the northern side of the Milk River valley in southeastern Alberta (Figure 1). Both include the upper part of the Foremost Formation and a large part of the overlying Oldman Formation. This report includes graphic logs of the measured sections, with outcrop gamma-ray curves; a detailed description of the sections (avoiding lithofacies interpretation but detailing stratigraphic context where appropriate) with selected photos; and the results of palynological work on a mudstone sample from the lower part of measured section T2-R6W4-02. The sections were measured in July–August 2008 (T2-R6W4-01) and July 2009 (T2-R6W4-02) using an Abney level attached to a 1.6 m Jacob staff.

2 Location

The measured sections are located approximately 3 km apart in the Pinhorn Provincial Grazing Reserve on the northern side of the Milk River valley in Twp. 2, Rge. 6, W 4th Mer. (abbreviated T2-R6W4; Figure 2). The base and top of each section are at the level of the lowest and highest exposed bedrock at that location. Appendix 1 contains detailed GPS location data.

3 Description

3.1 Foremost Formation

The lower part of each measured section (0 to 44.9 m in T2-R6W4-01; 0 to 42.2 m in T2-R6W4-02) is assigned to the Foremost Formation (Figures 3–6). The underlying, marine shale-dominated Pakowki Formation is not exposed in either of these sections, but Ogunyomi and Hills (1977) identified it at river level in the Milk River valley, 6 km to the west of section T2-R6W4-01 in Twp. 2, Rge. 7, W 4th Mer., where those authors measured a total thickness of approximately 65 m for the Foremost Formation. However, Russell and Landes (1940) placed the easternmost exposure of the Pakowki Formation on the Milk River farther west, in Twp. 2, Rge. 8, W 4th Mer. Russell and Landes (1940) considered marine shales exposed in the Milk River valley east of that point to form part of the Foremost Formation.

The basal part of each measured section (0 to 13.0 m in T2-R6W4-01; 0 to 11.8 m in T2-R6W4-02) consists of grey-brown silty mudstone with thin (generally <1 cm), very fine grained sandstone to siltstone interbeds showing gently inclined lamination, which increase in abundance upsection. Thin (generally <2 cm wide) sandstone dikes crosscut the lowermost part of this interval (Figure 7). Rare thicker sandstone units show hummocky cross-stratification (HCS). Mudstone-enclosed gutter casts, filled with very fine grained sandstone commonly showing HCS, tend to be more common in the upper part of the interval (Figure 8). A coquina consisting of disarticulated oyster valves forms laterally discontinuous lenses up to 6 cm thick at 9.0 m in T2-R6W4-02 (Figure 9). There is a 1.0 m thick sandstone, showing HCS, with locally abundant oyster valves at a similar level in T2-R6W4-01.

The lower mudstone-dominated interval is overlain by a thick, generally well-exposed unit of pale grey, very fine to fine-grained sandstone (13.0 to 20.8 m in T2-R6W4-01, Figure 5; 11.8 to 17.5 m in T2-R6W4-02) with a sharp base, locally with well-developed gutter casts. The lower part of the sandstone is swaley cross-stratified (SCS; Leckie and Walker, 1982; Figure 10). The upper part consists of amalgamated, erosionally based 30 to 50 cm thick units showing horizontal to low-angle planar stratification. The uppermost 30 to 40 cm of the sandstone is darker and carbonaceous (although with no obvious root traces).

The thick sandstone unit described above is overlain by a generally poorly exposed interval dominated by dark grey to brown mudstone (20.8 to 22.8 m in T2-R6W4-01; 17.5 to 21.6 m in T2-R6W4-02). In both measured sections, there is a thin coal seam (2 cm in T2-R6W4-01; 5 cm in T2-R6W4-02) at the base of this interval, immediately overlying the pale grey sandstone, and a second, thicker coal seam (23 cm in

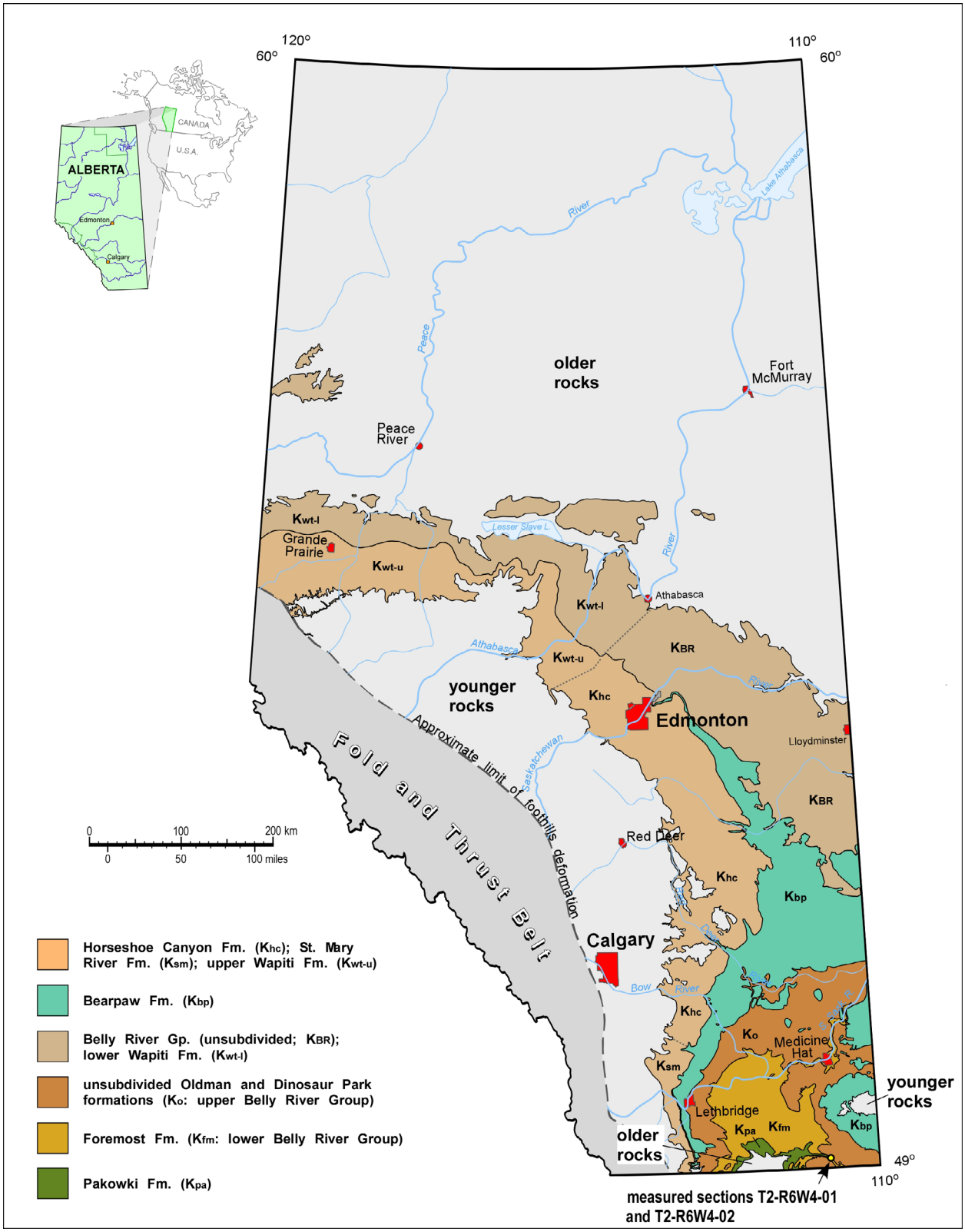

Figure 1. Simplified geological map (modified from Hamilton et al., 1999) showing the distribution of Belly River Group and surrounding rocks in Alberta and the location of measured outcrop sections T2-R6W4-01 and T2-R6W4-02.

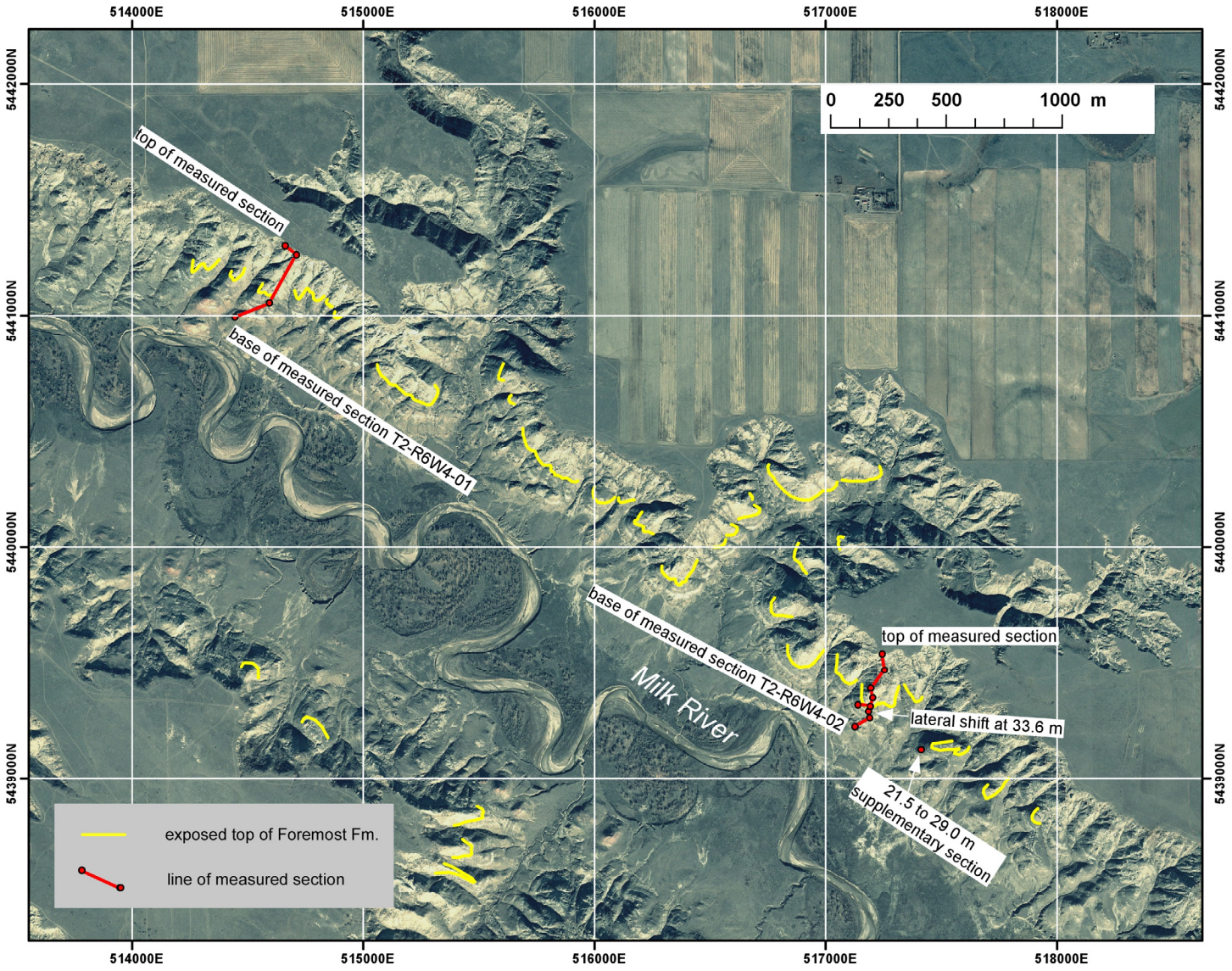

Figure 2. Location of measured sections T2-R6W4-01 and T2-R6W4-02 (southeastern Alberta) plotted on 1 m resolution orthorectified colour airphoto base with 1 km grid (UTM Zone 12, NAD 83). Position of exposed top of Foremost Formation is based on ground observation and colour airphoto interpretation.

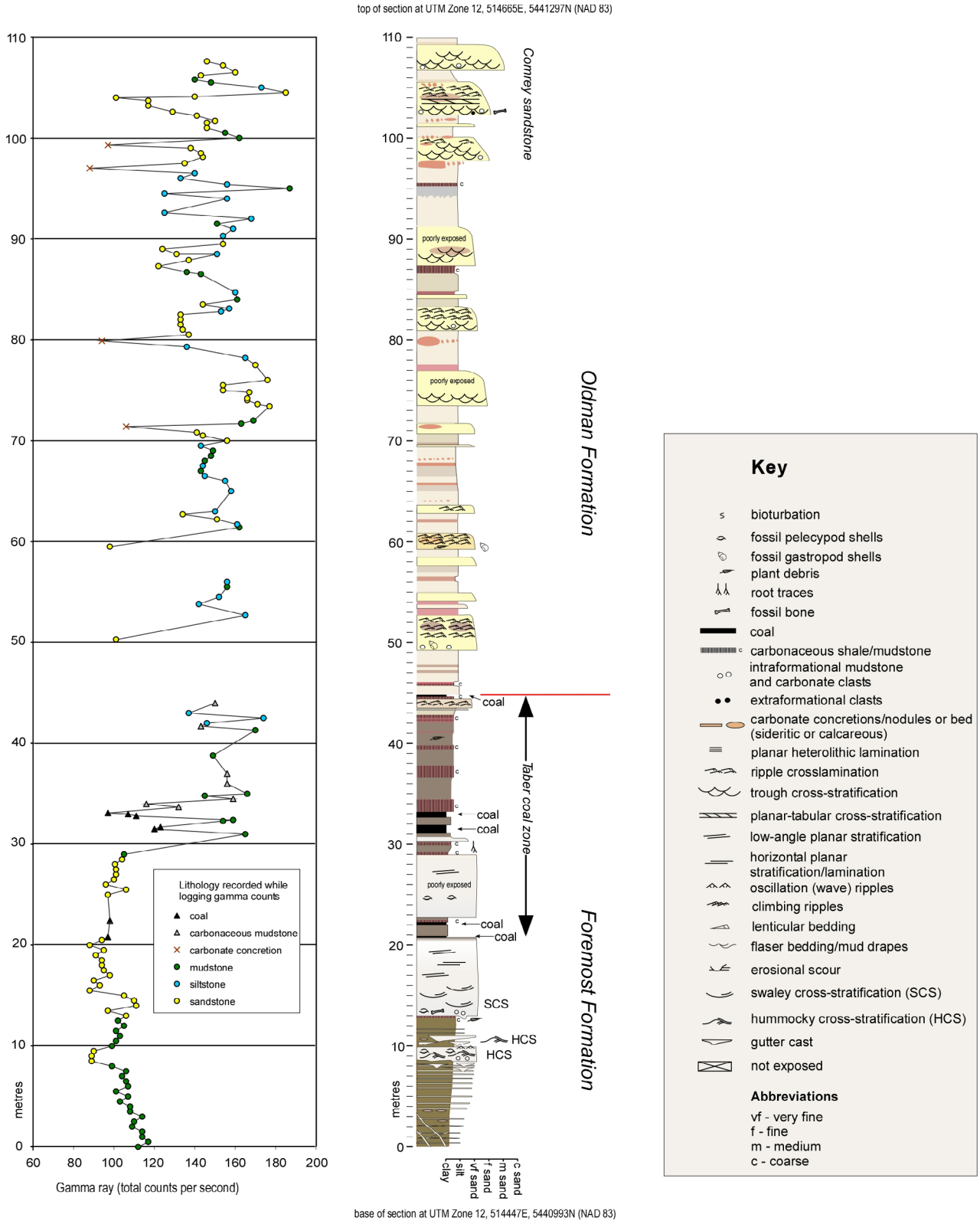

Figure 3. Graphic log of measured section T2-R6W4-01 (southeastern Alberta) with outcrop gamma-ray curve. See large-format version in Appendix 2 for descriptive notes.

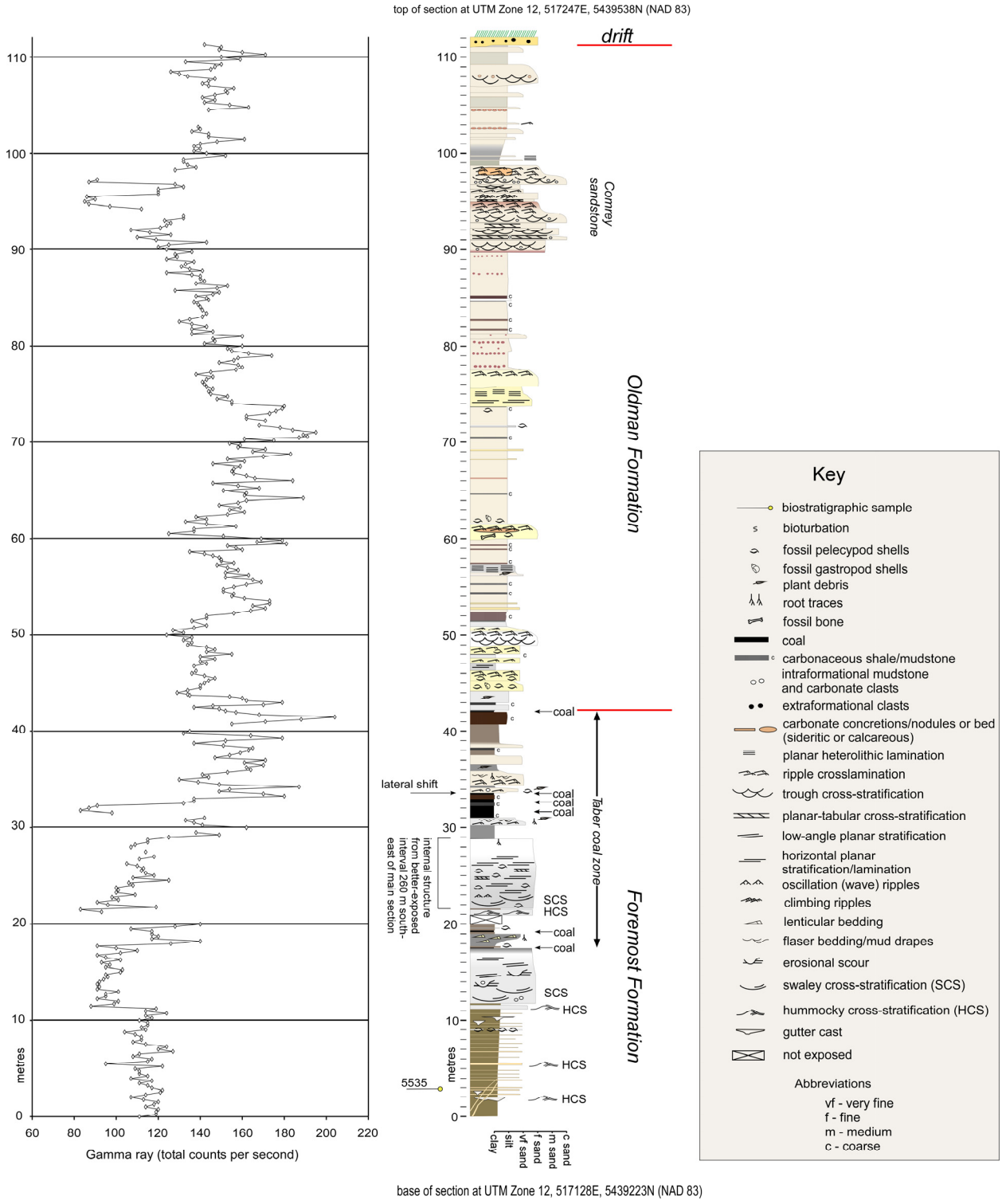

Figure 4. Graphic log of measured section T2-R6W4-02 (southeastern Alberta) with outcrop gamma-ray curve. See large-format version in Appendix 3 for descriptive notes.

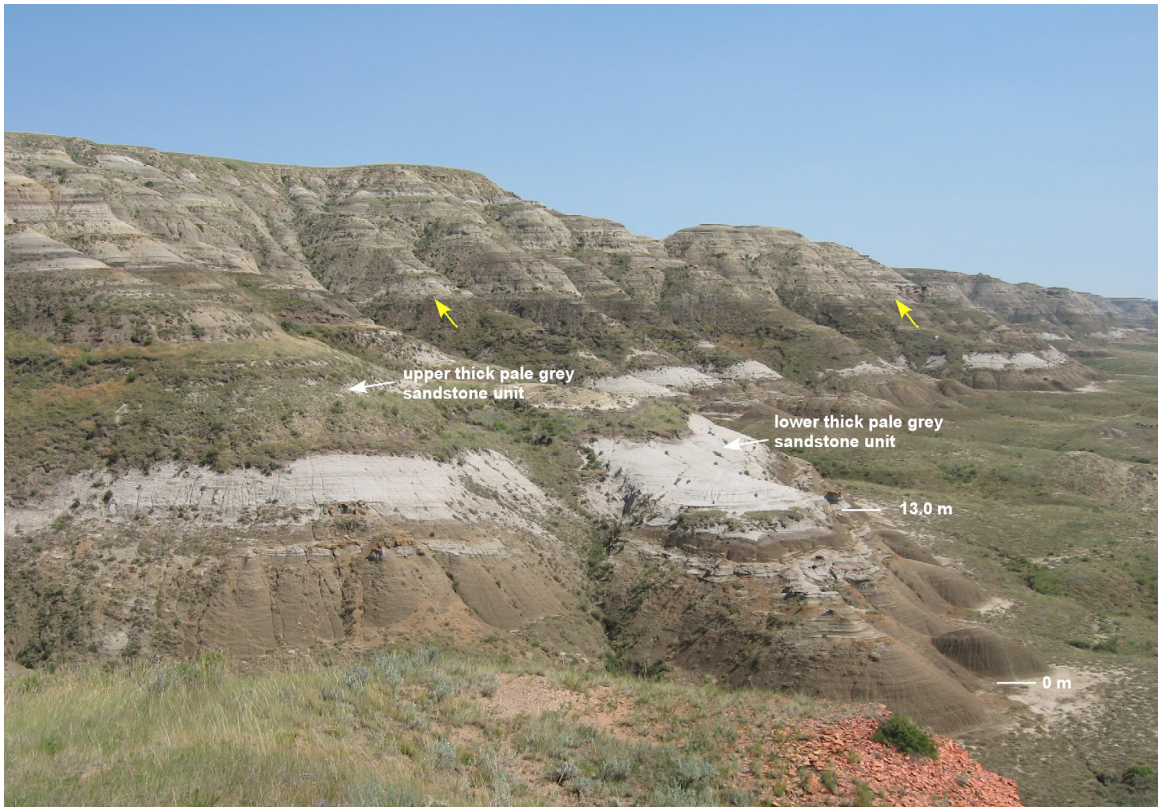

Figure 5. View looking east towards measured section T2-R6W4-01 (southeastern Alberta). Marked elevations correspond to Figure 3 graphic log. Yellow arrows indicate top of Foremost Formation. Note that the lower of the two thick, pale grey sandstone units in the Foremost Formation (base at 13.0 m) is well exposed, whereas the upper unit is generally poorly exposed.

T2-R6W4-01; 15 cm in T2-R6W4-02) higher in the section. A 60 cm thick sandstone unit showing HCS is present at the top of the mudstone-dominated interval in T2-R6W4-02. Trenching in measured section T2-R6W4-02 exposed a 1.3 m thick coarsening-upward package between the two coals, with dark grey mudstone at the base and crosslaminated lenses of very fine grained sandstone to siltstone increasing in abundance upward and becoming dominant towards the top.

The mudstone-dominated interval described above is overlain by a second, thick, pale grey, very fine to fine-grained sandstone unit (22.8 to 29.0 m in T2-R6W4-01; 21.6 to 28.9 m in T2-R6W4-02). This sandstone is generally more friable and less well exposed than the lower thick sandstone unit (Figures 5 and 6), and in T2-R6W4-01 little internal structure is discernible, apart from a band of disarticulated oyster valves and local traces of low-angle planar stratification. Although this upper sandstone unit is similarly poorly exposed in the main T2-R6W4-02 section, there is better exposure of the unit on a bluff 260 m to the southeast (supplementary section, Figure 2; internal structure interpolated into Figure 4 graphic log). Here, the lower part of the sandstone exhibits SCS, with thin wave-ripple crosslaminated intervals and few or no oysters, and the middle part shows horizontal planar stratification, with planar cross-stratified lenses (some with herringbone reversals of foreset dip) and abundant disarticulated oyster and other bivalve shells. The upper 3 m of the unit are white (leached) and more weathered, and internal structure is less clear. Root traces (or possibly simple vertical burrows) are locally present in the uppermost part of the sandstone.

The uppermost part of the Foremost Formation (29.0 to 44.9 m in T2-R6W4-01; 28.9 to 42.2 m in T2-R6W4-02) consists mainly of dark grey to grey-brown mudstone and red to purplish brown carbonaceous

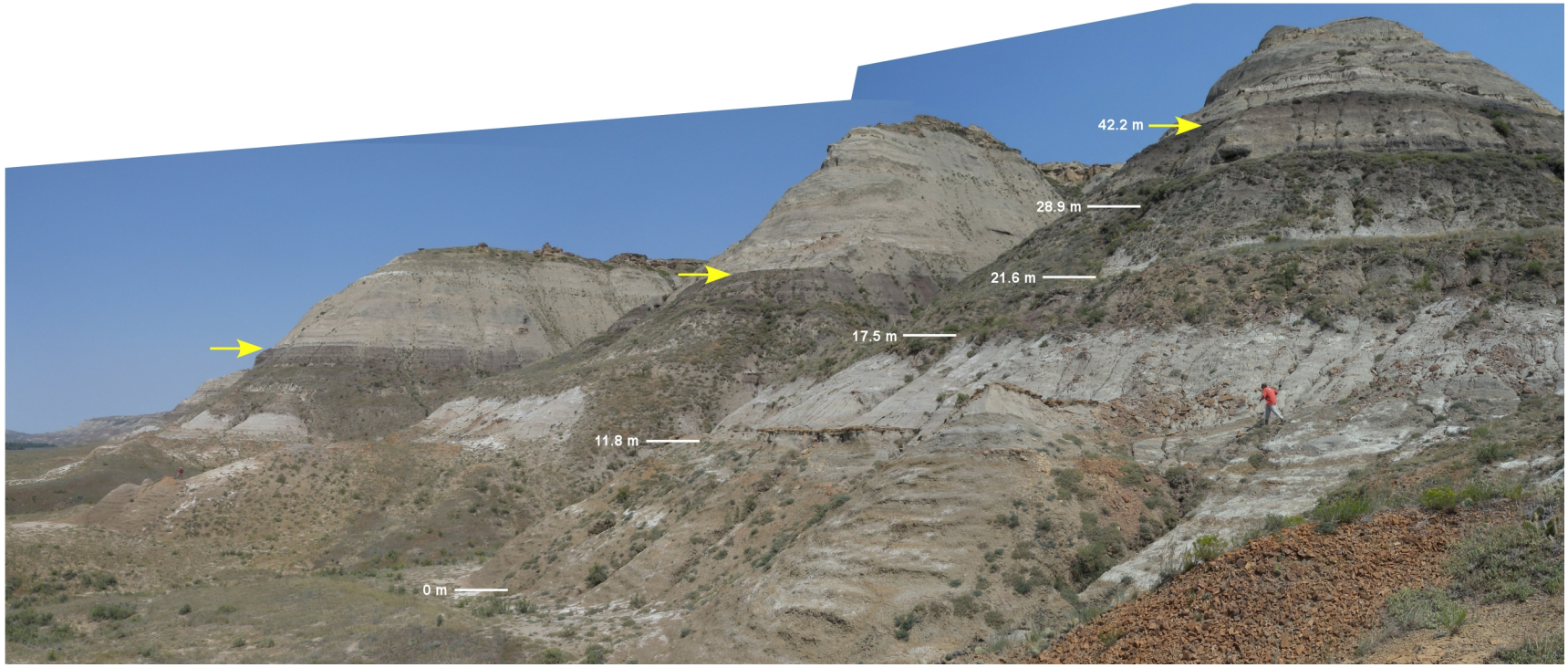

Figure 6. North side of Milk River valley from viewpoint at 517114E, 5439244N (UTM Zone 12, NAD 83). Section T2-R6W4-02 was measured on the nearest of the three bluffs. Marked elevations correspond to Figure 4 graphic log. Figure at lower right for scale. Yellow arrows indicate top of Foremost Formation.

Figure 7. Thin sandstone dikes crosscut darker mudstone with thin sandstone to siltstone units in Foremost Formation in basal part of measured section T2-R6W4-01 (southeastern Alberta).

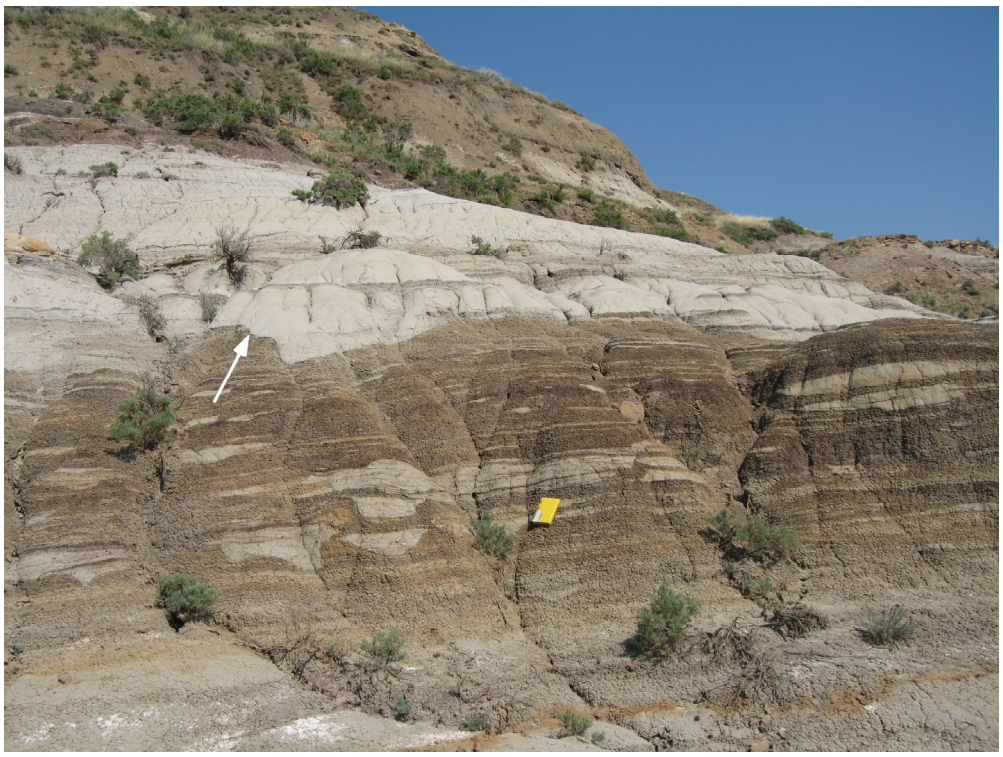

Figure 8. Sandstone-filled gutter casts in Foremost Formation mudstone, below base of thick sandstone unit at 13.0 m (arrow indicates base) in measured section T2-R6W4-01 (southeastern Alberta). Notebook for scale (19 cm high).

Figure 9. Bedding plane view of top of oyster coquina, 180 m northwest of measured section T2-R6W4-02 (southeastern Alberta) at 517031E, 5439370N (UTM Zone 12, NAD 83). Correlates to Foremost Formation oyster coquina at 9.0 m level in measured section T2-R6W4-02.

Figure 10. Swaley cross-stratification (at level of 19 cm high yellow notebook) in lower part of pale grey sandstone at 11.8 to 17.5 m level in measured section T2-R6W4-02 (Foremost Formation, southeastern Alberta).

mudstone, with two (T2-R6W4-01) or three (T2-R6W4-02) relatively thick (up to 1.2 m) coal seams situated close together in the lower part of the interval and a single thinner coal seam (20 cm in T2-R6W4-01; 8 cm in T2-R6W4-02) at the top. This interval also includes a number of fining-upward, very fine grained sandstone units. These are more abundant and thicker (up to 1.5 m) in T2-R6W4-02, where they commonly show ripple crosslamination, in some cases with mud flasers and root traces towards the top.

The upper part of the Foremost Formation, between and including the lowermost and uppermost coal seams (20.8 to 44.9 m in T2-R6W4-01; 17.5 to 42.2 m in T2-R6W4-02; Figures 3 and 4), is considered to represent the Taber coal zone (Crockford, 1949; Macdonald et al., 1987).

Results of palynological work on a sample from the Foremost Formation, 2.9 m above the base of measured section T2-R6W4-02 (see Figure 4 for location), are detailed in Appendix 4.

3.2 Oldman Formation

The upper part of each measured section is assigned to the Oldman Formation (Figures 3 and 4) as defined by Russell and Landes (1940) and in the more restricted sense of Eberth and Hamblin (1993).

Russell and Landes (1940) initially named the Oldman Formation as a substitute term for the 'Pale beds' of Dowling (1917), noting that "the top of the Foremost is placed at the upper limit of a zone of dark shale rich in carbonaceous beds and coal seams" (the Taber coal zone) in the Milk River valley, where "the colour contrast between the dark brown of the upper Foremost beds and the pale grey of the Oldman strata is very striking." In more recent studies, Eberth (2002, 2005) has identified a 'Herronton sandstone zone' lying above the Taber coal zone, but with compositional affinities to the Foremost Formation rather than the overlying Oldman Formation sandstones (Eberth 2002, 2005). This led Eberth (2002, 2005) to include his Herronton sandstone zone in the Foremost Formation, adjusting the boundary upsection compared to earlier work that followed Russell and Landes (1940) in placing the contact at the top of the Taber coal zone (e.g., Eberth and Hamblin, 1993). However, the Herronton sandstone zone could not be identified in T2-R6W4-01 and T2-R6W4-02 (see discussion of gamma-ray data below), and the boundary is therefore placed as indicated by Russell and Landes (1940). In both sections, the marked colour change takes place at the top of the uppermost coal seam of the Taber coal zone and, for the purposes of this report, this is taken to mark the formation boundary (Figures 5 and 6).

In both sections, the Oldman Formation consists largely of siltstone, muddy siltstone and minor mudstone. Sandstone beds up to 4 m thick are present throughout the exposed Oldman Formation as isolated beds or packages of several amalgamated units. Intervals dominated by resistant, well-cemented sandstone towards the tops of the measured sections (Figures 11 and 12) represent the Comrey sandstone of Russell and Landes (1940, p. 67). According to Russell and Landes (1940, p. 69), the thickness of the interval "between the base of the Comrey sandstone and the top of the Foremost" on the north side of the Milk River valley "remains constant at between 140 and 150 feet" (42.7 and 45.7 m). In measured section T2-R6W4-02, the base of the Comrey sandstone is well defined at the base of a 9 m thick amalgamated sandstone package at 89.7 m (47.5 m above the top of the Foremost Formation). Although this package is thinner than the 50 ft. (15 m) thick Comrey sandstone section measured by Russell and Landes (1940, p. 68) in Twp. 2, Rge. 7, W 4th Mer., the overlying siltstone-dominated interval up to the base of drift at 111.0 m does include a higher proportion of sandstone units (mainly thin) than is present in the siltstones below 89.7 m. The Comrey sandstone is less well defined as a discrete unit in T2-R6W4-01, where it is represented by a number of individual thick sandstone beds separated by thinner siltstone and mudstone intervals between 97.8 m and the top of the measured section.

Oldman Formation siltstone and mudstone intervals are mainly pale grey to grey-brown weathering. Generally, thin, darker, commonly carbonaceous, red-brown or grey siltstone bands are common below

Figure 11. Upper part of measured section T2-R6W4-02 (southeastern Alberta) looking east from viewpoint at 517122E, 5439486N (UTM Zone 12, NAD 83). Arrows indicate base of Comrey sandstone. Figures at upper left (circled) are at the top of the measured section.

the Comrey sandstone (Figure 12). Horizons of purple-red sideritic carbonate nodules with diffuse margins are fairly abundant in siltstone intervals above the lower 20 m of the formation. A relatively continuous (although passing laterally to diffuse nodules), 35 cm thick, calcite-cemented interval developed in siltstone immediately below the base of the Comrey sandstone (97.8 m) in measured section T2-R6W4-01 is interpreted as a calcrete (see Troke, 1993). Similar, but thinner, intervals are present in siltstone intervals higher in this section. Apart from the colour banding, siltstones and mudstones are generally structureless in appearance, although rare, finely laminated mudstone intervals do occur (e.g., at 46.5 and 99.5 m in T2-R6W4-02).

Oldman Formation sandstone units situated below the Comrey sandstone are generally yellow weathering, very fine (rarely fine) grained and sharp based, with gradational, normally graded tops. Thicker units show trough cross-stratification, commonly passing up to unidirectional ripple crosslamination, and where internal structure is clear, thinner beds are generally ripple crosslaminated. Towards the base of the Oldman Formation, some sandstone beds contain abundant whole or fragmentary bivalve and/or gastropod shells, mainly in their basal divisions, which may also contain fossil bone and/or carbonate-cemented intraclasts.

Sandstone units within the Comrey sandstone package show trough or planar-tabular cross-stratification (Figure 13), trough cross-stratification passing up to ripple crosslamination, or climbing ripple crosslamination. They tend to be coarser grained than sandstones within the underlying part of the Oldman Formation (up to medium- to coarse-grained). Pale, commonly concentrically laminated, carbonate intraclasts (some likely to represent reworked caliche glaebules; see Troke, 1993) are abundant in basal lags, and also occur along cross-set boundaries and on foresets in many units. Fossil bone and a single 7 cm chert cobble were found at the base of the thickest Comrey sandstone bed in T2-R6W4-01.

4 Gamma-Ray Data

The methodology for collecting the outcrop gamma-ray data (shown in Figures 3 and 4) is detailed in Appendix 5.

Gamma-ray counts show a steady decrease upward through the mudstone-dominated basal intervals (0 to 13.0 m in T2-R6W4-01; 0 to 11.8 m in T2-R6W4-02) of both measured sections, consistent with the observed coarsening-upward trend. The two thick overlying Foremost Formation sandstone intervals show consistently lower gamma counts than the relatively low values from the basal mudstones. There appears to be a significant increase in gamma-ray values at the top of the upper thick sandstone unit (29.0 m in T2-R6W4-01; 28.9 m in T2-R6W4-02), although there are some higher counts for mudstones from the coal-bearing interval (17.5 to 21.6 m) below this sandstone in T2-R6W4-02. The difference in gamma-ray counts for units with similar lithology and grain size above and below this shift suggests that a compositional difference may be the controlling factor. The higher gamma-ray counts in the uppermost part of the Foremost Formation (29.0 to 44.9 m in T2-R6W4-01; 28.9 to 42.2 m in T2-R6W4-02) are punctuated by low values for the thicker coals in the lower part of the interval. Gamma-ray counts for sandstone units in the upper part of the Foremost Formation in section T2-R6W4-02 are lower than those for mudstone, but remain significantly higher than those for sandstone intervals in the lower part of the Foremost Formation section. The Herronton sandstone zone, defined as a sandstone unit or package above the Taber coal zone but with relatively low gamma-ray values similar to those for underlying Foremost Formation strata (Eberth, 2002, 2005), could not be identified in these measured sections.

The Oldman Formation shows high gamma-ray counts, similar to those for the uppermost Foremost Formation, again with slightly lower values for sandstone than for siltstone and mudstone. The lowest values are generally recorded from carbonate concretion horizons and intervals rich in carbonate intraclasts. In both measured sections there are indications of a steady, overall decrease in gamma-ray counts up towards the Comrey sandstone, suggesting a broad coarsening-upward trend.

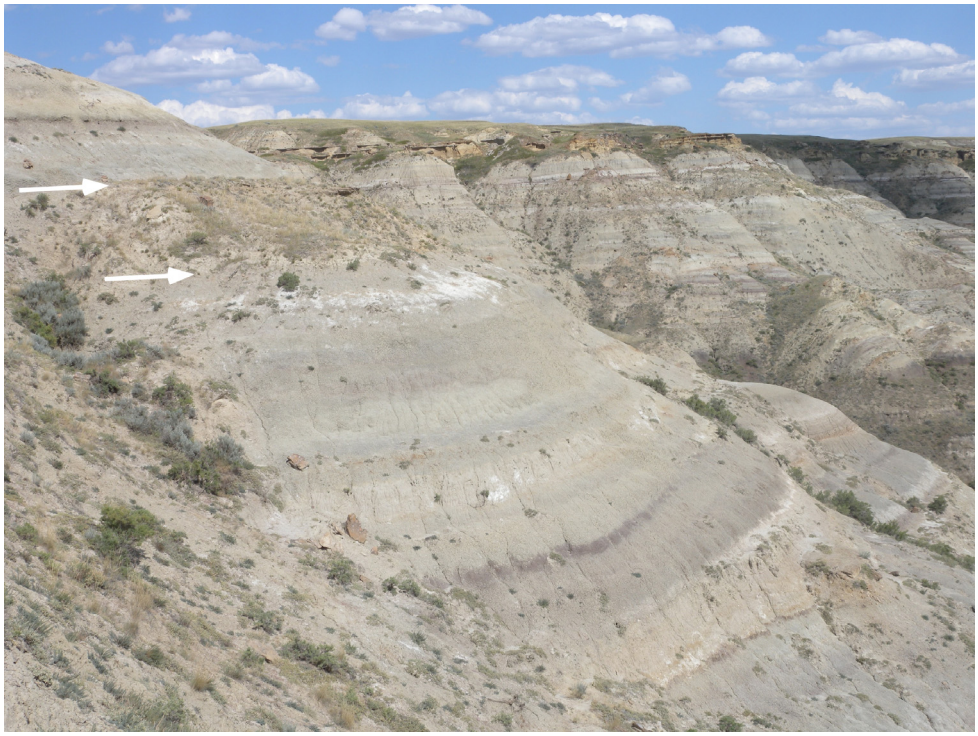

Figure 12. Oldman Formation exposed in bluff located east-southeast from line of measured section T2-R6W4-02 (southeastern Alberta). Base of upper sandstone package in near bluff (base and top indicated by arrows) correlates to base of sandstone package at 73.7 m in measured section. The resistant interval visible near the top of the bluffs in the middle distance is the Comrey sandstone of Russell and Landes (1940).

Figure 13. Trough cross-stratified medium- to coarse-grained sandstone of the Comrey sandstone (Oldman Formation) at 92.0 m in measured section T2-R6W4-02 (southeastern Alberta). Hammer is 30 cm long.

5 Summary

Measured outcrop sections T2-R6W4-01 and T2-R6W4-02 both include the upper part of the Foremost Formation and a large part of the overlying Oldman Formation. The lowermost part of the exposed Foremost Formation interval consists mainly of dark grey-brown silty mudstone with thin sandstone and siltstone interbeds. Rare, thicker sandstone beds and isolated sand-filled gutter casts commonly show HCS. The lower mudstone-dominated interval is overlain by a thick sandstone unit showing SCS. A coal seam at the top of the thick sandstone unit marks the base of the Taber coal zone, which forms the upper part of the exposed Foremost Formation interval. The Taber coal zone consists mainly of mudstone and siltstone (which are commonly dark and carbonaceous); a number of coal seams (up to 1.2 m thick); relatively thin (up to 1.5 m thick), commonly ripple crosslaminated sandstone units; and in the lower part, a thick sandstone unit showing SCS, horizontal planar stratification and cross-stratification.

The Oldman Formation is distinctly paler in colour than the underlying Foremost Formation. It consists mainly of pale grey to grey-brown muddy siltstone with subordinate fine- to very fine grained, fining-upward sandstone units up to 4 m thick, which commonly show trough cross-stratification and/or ripple crosslamination. Sandstone-dominated intervals in the upper part of each measured section represent the Comrey sandstone of Russell and Landes (1940).

In both measured sections, outcrop gamma-ray counts are relatively low for the lower part of the exposed Foremost Formation, with an abrupt shift to higher counts at the top of the thick sandstone unit in the lower part of the Taber coal zone, which is generally sustained upwards through the overlying Oldman Formation. The marked difference in gamma-ray counts for units with similar lithology and grain size above and below this shift suggests that a compositional difference may be the controlling factor.

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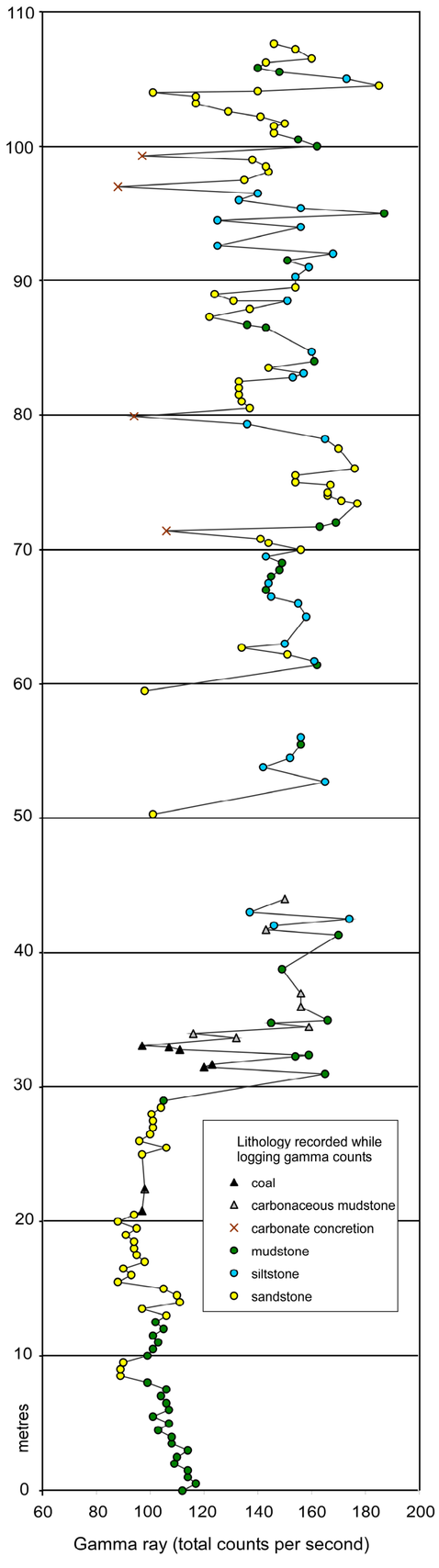
Appendix 1 – GPS Location Data for Measured Sections T2-R6W4-01 and T2-R6W4-02

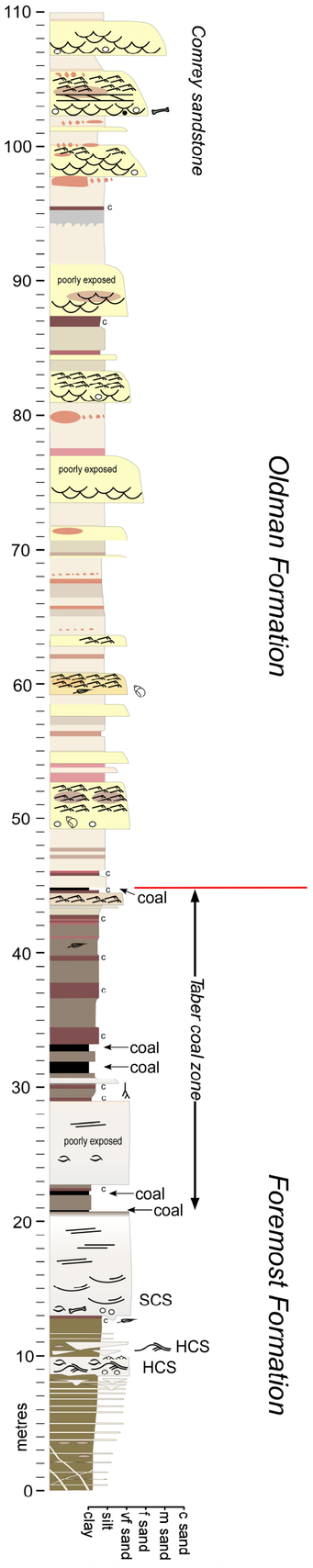
The GPS location data for measured sections T2-R6W4-01 and T2-R6W4-02 in southeastern Alberta were obtained using Garmin® GPSMAP® 60CSx hand-held units. The UTM co-ordinates are Zone 12, NAD 83. The ± values indicate estimates of horizontal error generated by the GPS units.

Easting	Northing	Horizontal Error (±)	Elevation (m)	Comment
514447	5440993	1.6	874	base of T2-R6W4-01 measured section (0.0 m) – 1st GPS unit
514447	5440992	2.0	874	base of T2-R6W4-01 measured section (0.0 m) – 2nd GPS unit
514506	5440995	3.1	881	15.7 m in T2-R6W4-01 measured section
514596	5441054	4.8	905	32.5 m in T2-R6W4-01 measured section
514652	5441189	3.3	952	74.0 m in T2-R6W4-01 measured section
514714	5441258	1.6	982	104.0 m in T2-R6W4-01 measured section
514661	5441291	2.5	985	106.8 m in T2-R6W4-01 measured section
514665	5441297	1.7	986	110.0 m in T2-R6W4-01 measured section (top of section)
517128	5439223	5.0	874	base of T2-R6W4-02 measured section (0.0 m)
517193	5439259	4.0	888	21.5 m in main T2-R6W4-02 measured section
517415	5439122	7	893	21.5 m level in short supplementary section (up to 29.0 m – poorly exposed in main section) 260 m southwest of main T2-R6W4-02 measured section
517187	5439287	12	910	33.6 m in main T2-R6W4-02 measured section (before lateral shift)
517142	5439316	6	909	33.6 m in T2-R6W4-02 measured section (after lateral shift)
517194	5439308		915	42.2 m in T2-R6W4-02 measured section (top of Foremost Formation)
517207	5439346		940	64.7 m in T2-R6W4-02 measured section
517197	5439391		963	89.7 m in T2-R6W4-02 measured section (base of Comrey sandstone)
517258	5439466		976	100.5 m in T2-R6W4-02 measured section
517247	5439538	2.7	986	111.0 m in T2-R6W4-02 measured section (base of drift)

Appendix 2 – Graphic Log of Measured Outcrop Section T2-R6W4-01 (Southeastern Alberta) with Outcrop Gamma-Ray Curve. Large-Format Version of Figure 3 with Descriptive Notes.

top of section at UTM Zone 12, 514665E, 5441297N (NAD 83)





yellow-grey–weathering, m-grained (locally m-c–grained) sandstone, fining up, trough cross-stratified, carbonate (caliche?) intraclasts in 3 to 4 cm thick basal lag and along cross-set boundaries

green-brown siltstone fining up to brownish green silty mudstone

yellow- to grey-weathering, f-grained sandstone, fining up, trough cross-stratification overlain by planar-tabular cross-stratification and ripple crosslamination; some large discoidal concretions; caliche glaebules, bone and 7 cm chert cobble in basal lag

brownish green muddy siltstone with carbonate nodules

mid-grey–brown silty mudstone

yellow- to grey-weathering, f-grained sandstone, fining up, trough cross-stratification overlain by ripple crosslamination; discontinuous calcrete horizons at top and bottom of unit; sparse carbonate (caliche?) intraclasts in sandstone

orange-weathering calcite-cemented interval (calcrete?) passing laterally to diffuse nodules

mid-grey–brown muddy siltstone
dark red carbonaceous siltstone
mid-grey muddy siltstone with distinct, irregular lower contact

mid-grey–brown muddy siltstone

pale yellow-grey–weathering, vf grained sandstone, slight fining up, trough cross-stratification clear in carbonate concretions, otherwise friable and poorly exposed

dark red carbonaceous silty mudstone

mid-green–brown muddy siltstone
dark red-brown silty mudstone
poorly exposed, friable vf grained sandstone

pale yellow-grey–weathering, vf grained sandstone, slight fining up, trough cross-stratification overlain by ripple crosslamination, sparse intraclasts (caliche?) in lower part

orange-weathering carbonate concretions/nodules

mid-grey–brown muddy siltstone

dark red-brown muddy siltstone

sharp-based, pale yellow-weathering, f-grained sandstone, fining up to vf grained sandstone, trough cross-stratification in lower part, upper part friable and poorly exposed

blocky weathering, grey-green muddy siltstone

sharp-based, pale yellow-grey–weathering, vf grained sandstone

grey-brown silty mudstone
carbonate nodules

grey-brown and red-brown silty mudstone and muddy siltstone

grey-brown muddy siltstone
carbonate nodules
sharp-based, pale yellow-weathering, vf grained sandstone, largely friable

dark red-brown muddy siltstone
grey-brown muddy siltstone
yellow-brown–weathering, vf grained sandstone, slight fining up, basal 30 cm with thin-walled gastropod shells and wood fragments, upper part ripple crosslaminated, large carbonate concretions

sharp-based, vf grained sandstone

dark red-brown silty mudstone

grey-brown muddy siltstone
sharp-based, vf grained sandstone, slight fining up

red-brown muddy siltstone

pale yellow-weathering, vf grained sandstone, slight fining up; basal 30 cm locally rich in thin-walled gastropod shells/shell debris, intraclasts and plant debris; upper part ripple crosslaminated with some carbonate concretions

grey-brown muddy siltstone
poorly defined, darker, reddish intervals

dark red-brown carbonaceous shale with coal lenses at base
grey-brown (pale yellow-grey–weathering) muddy siltstone
20 cm coal
vf grained sandstone, crosslamination to low-angle lamination, carbonaceous intervals
poor exposure
red-brown carbonaceous shale, locally with coal lenses

medium grey-brown mudstone, finely fissile, minor plant debris
dark purplish brown carbonaceous shale, locally with coal lenses

medium grey-brown mudstone
dark purplish brown carbonaceous shale, moderately fissile

blocky weathering, grey-brown mudstone, noncarbonaceous

dark red-brown carbonaceous shale with coal lenses up to l cm (proportion decreasing upwards), moderately fissile

55 cm coal, gradational upper contact
blocky weathering, medium brown-grey mudstone, minor silt content
74 cm coal, sharp upper contact
brown mudstone, finely fissile
vf grained sandstone, friable and poorly exposed
dark brown to mid-grey–brown, blocky weathering silty mudstone and carbonaceous shale, local root traces

pale grey to brown weathering, vf grained sandstone, largely friable and poorly exposed, traces of low-angle planar stratification locally apparent in upper part

concentration of disarticulated oyster valves in sandstone

23 cm coal overlain by dark brown carbonaceous shale with coal lenses

2 cm coal overlain by dark grey-brown fissile mudstone

pale grey vf grained sandstone; low-angle to horizontal planar stratification in amalgamated 50 to 30 cm thick units with thin silty sandstone tops

pale grey vf to f-grained sandstone with SCS, sharp base locally with gutter casts; oyster shell fragments, bone and intraclasts in basal 50 cm

grey-brown silty mudstone, reddish and carbonaceous towards top

lenticular vf grained sandstone units with HCS, and isolated gutter casts filled with vf grained sandstone in grey-brown silty mudstone

pale grey vf grained sandstone, sharp erosional base with gutter casts, HCS locally clear, mud clasts at base, oyster shells locally abundant in upper part, wave ripples at top

thin, pale grey vf grained sandstone units interbedded with brown silty mudstone; gutter casts (commonly isolated) filled with vf grained sandstone

mid-grey–brown silty mudstone with paler siltstone and vf grained sandstone units up to 4 cm, minor discoidal carbonate concretion horizons

mid- to dark grey-brown mudstone with parallel-sided to lenticular siltstone to vf grained sandstone units up to 2 cm, crosscutting sandstone dikes up to 6 cm across

Key

- biostratigraphic sample
- bioturbation
- fossil pelecypod shells
- fossil gastropod shells
- plant debris
- root traces
- fossil bone
- coal
- c — carbonaceous shale/mudstone
- intraformational mudstone and carbonate clasts
- extraformational clasts
- carbonate concretions/nodules or bed (sideritic or calcareous)
- planar heterolithic lamination
- ripple crosslamination
- trough cross-stratification
- planar-tabular cross-stratification
- low-angle planar stratification
- horizontal planar stratification/lamination
- oscillation (wave) ripples
- climbing ripples
- lenticular bedding
- flaser bedding/mud drapes
- erosional scour
- swaley cross-stratification (SCS)
- hummocky cross-stratification (HCS)
- gutter cast
- not exposed

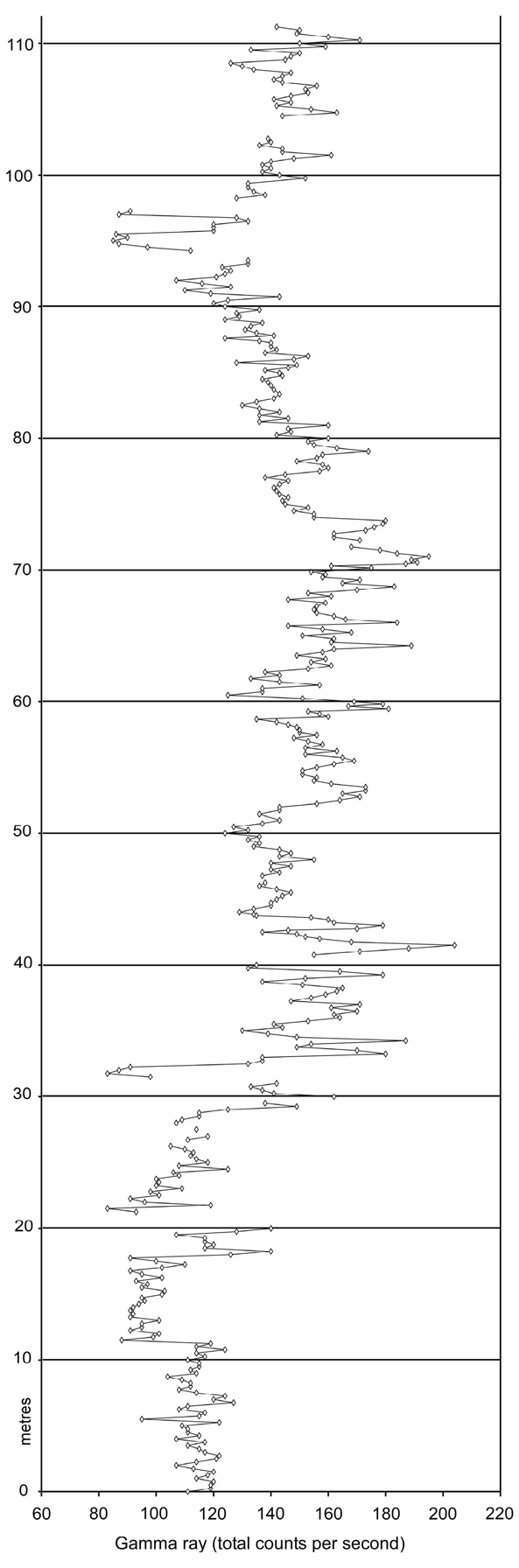
Abbreviations

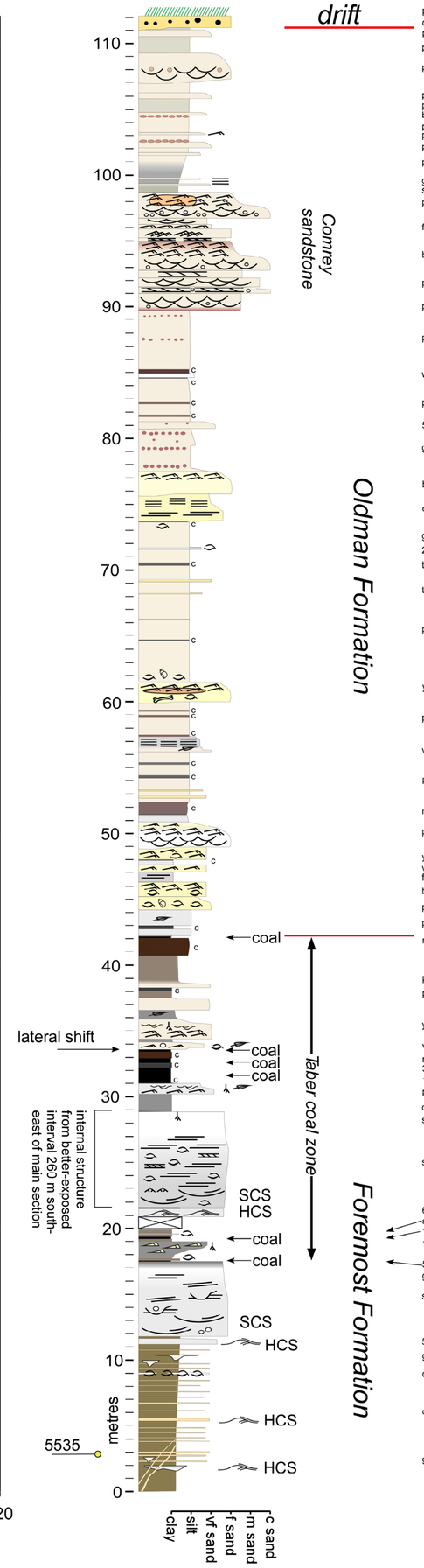
vf - very fine
f - fine
m - medium
c - coarse

base of section at UTM Zone 12, 514447E, 5440993N (NAD 83)

Appendix 3 – Graphic Log of Measured Outcrop Section T2-R6W4-02 (Southeastern Alberta) with Outcrop Gamma-Ray Curve. Large-Format Version of Figure 4 with Descriptive Notes.

top of section at UTM Zone 12, 517247E, 5439538N (NAD 83)





plains level
drift: unconsolidated yellow-grey fine sand with cobbles
pale yellow-grey vf grained sandstone

pale grey-green muddy siltstone

pale yellow-grey f-grained fining up to vf grained sandstone, sharp erosional base, abrupt top, lower part trough cross-stratification, round (cannon-ball) calcite concretions up to 25 by 10 cm in middle part of unit

pale yellow-grey vf grained sandstone
pale grey-green muddy siltstone
bench-forming laterally continuous sideritic concretion horizon
pale grey muddy siltstone
pale yellow vf grained sandstone, ripple crosslamination
pale yellow vf grained sandstone, no clear internal structure; overlain by laterally continuous 20 cm thick sideritic concretion horizon

pale grey muddy siltstone

grey laminated siltstone and mudstone with thin pale grey vf grained sandstone to siltstone units
sticky dark grey-green mudstone
pale buff c-grained fining up to f-grained sandstone, trough cross-stratification with abundant carbonate intraclasts overlain by ripple crosslamination, calcite-cemented hoodoos at top

f- and vf grained sandstone, planar-tabular and trough cross-stratification and climbing ripple crosslamination

buff-yellow to reddish c-grained fining up to f-grained sandstone, trough cross-stratification with abundant carbonate intraclasts overlain by ripple crosslamination

pale buff m- to c-grained sandstone, planar-tabular and trough cross-stratification, abundant carbonate intraclasts

pale buff f- to m-grained sandstone, trough cross-stratification with carbonate intraclasts, rusty red indurated basal zone

pale grey muddy siltstone, purple-red sideritic nodules with diffuse margins in discrete 10 to 20 cm horizons

white indurated siltstone with gradational lower contact overlain by resistant dark red carbonaceous muddy siltstone

pale grey muddy siltstone with thin red-brown carbonaceous intervals

50 cm vf grained sandstone, purple-red sideritic nodules in upper part

grey muddy to sandy siltstone, purple-red sideritic nodules with diffuse margins mainly in discrete horizons

buff-yellow f-grained, fining up sandstone, erosional base, ripple crosslamination towards top

orange-yellow f- to vf grained sandstone with flat lamination, passing up to sandstone/siltstone heterolithic lamination

grey-brown muddy siltstone, bivalve shell fragments in upper part, 1 cm carbonaceous interval at top
20 cm vf grained sandstone to siltstone, indistinct upper and lower contacts, bivalve shells
thin, dark grey, very carbonaceous interval

thin pale yellow vf grained sandstone units, indistinct upper and lower contacts, no clear internal structure

pale grey-brown muddy siltstone with minor thin dark grey (carbonaceous) and red-brown intervals

yellow to orange-yellow, fining up, f- to vf grained sandstone with sharp erosional base, bivalve shells and fossil bone in lower part, upper part ripple crosslaminated and locally carbonate cemented; gradationally overlain by grey-brown siltstone with abundant whole and fragmentary gastropod and bivalve shells

pale grey to grey-brown muddy siltstone with thin red-brown carbonaceous intervals

vf grained sandstone with plant debris passing up to interlaminated vf grained sandstone and siltstone

pale grey to grey-brown muddy siltstone with thin darker grey, carbonaceous intervals and two thin paler, yellow-grey vf grained sandstone units

resistant red-brown, carbonaceous silty mudstone

pale grey to yellowish, fining up, f- to vf grained sandstone with sharp erosional base, trough cross-stratification passing up to ripple crosslamination; gradationally overlain by pale grey silty mudstone, carbonaceous at top

yellow vf grained sandstone, ripple crosslaminated, bivalve shells in lower part
vf grained sandstone, ripple crosslamination; passing up to grey mudstone, carbonaceous at top
flat-laminated grey-green mudstone

buff-yellow vf grained to silty sandstone, bivalve shells in lower part, ripple crosslaminated upper part

pale yellow-grey vf grained sandstone fining up to silty sandstone, abundant whole and fragmentary gastropod and bivalve shells

pale grey siltstone with woody fragments, 30 cm carbonaceous mudstone interval in lower part

resistant red-brown carbonaceous siltstone to silty mudstone overlain by 7 to 8 cm coal, in turn overlain by 8 to 10 cm dark grey mudstone with plant debris

poorly exposed, sharp-based, yellow-grey vf grained sandstone; passing up to slightly carbonaceous grey-brown silty mudstone

poorly exposed, pale yellow-grey vf grained sandstone to siltstone, some plant debris; passing up to dark grey-brown mudstone, which is red-brown and carbonaceous (locally coaly) in uppermost 20 cm

yellow-grey to red-brown vf grained sandstone, ripple crosslamination, with silty mudstone flasers and root traces towards top; passing up to mid-grey, slightly silty mudstone with plant debris
vf grained sandstone to siltstone, ripple crosslamination, with plant debris, bivalves, coaly fragments and mudclasts; passing up to dark grey, noncarbonaceous mudstone

resistant red-brown carbonaceous shale overlain by 15 cm coal
35 cm resistant grey-brown coaly shale overlain by 35 cm coal
1 to 2 cm coaly shale overlain by 1.2 m coal
pale grey vf grained sandstone fining up to siltstone, low-angle crosslamination, with millimetre-thick mud flasers, plant debris and root traces in upper part

dark grey mudstone (no silt), minor comminuted shell debris

sedimentary structures unclear in white and more friable (leached) upper part of sandstone unit; root traces (possibly vertical burrows?) locally present in uppermost part

sharp-based, pale grey f- to vf grained sandstone; disarticulated oyster and other bivalve shells abundant throughout lower two-thirds of unit; SCS with minor wave-rippled horizons in lower part passing up to horizontal planar stratification with small-scale planar cross-stratified lenses (wedge sets)

60 cm vf grained sandstone showing HCS, well-cemented, minor mudstone intraclasts at base
sticky, slightly silty, mid brown claystone with 3 to 4 cm, pale buff, fine broken shell hash unit
15 cm coal overlying 18 cm dark brown mudstone with yellow veining
15 cm brown silty mudstone with abundant thin-walled bivalve shell debris gradationally overlain by 1.3 m coarsening up package with dark grey mudstone (no silt) at base, crosslaminated yellow vf grained sandstone to siltstone lenses increasing in abundance upward and dominating at top, root traces towards top
5 cm coal immediately above sandstone
gradationally based, 40 cm thick, dark purplish grey indurated zone at top of sandstone (carbonaceous but no obvious root traces)

sharp-based, pale grey f- to vf grained sandstone, SCS (with internal scours) passing up to low-angle to horizontal planar stratification, minor orange sideritic intraclasts in lower part

54 cm f- to vf grained sandstone with HCS, sharp base and sharp undulating top, calcite cemented
grey-brown silty mudstone with minor thin (generally <1 cm) vf grained sandstone to siltstone interbeds and thicker, commonly isolated gutter casts filled with f- to vf grained sandstone showing HCS
oyster coquina with vf grained sandstone matrix forms laterally discontinuous lenses up to 6 cm thick

dark grey-brown silty mudstone with thin (generally <1 cm, rarely up to 18 cm) vf grained sandstone to siltstone interbeds showing gently inclined lamination (HCS in thicker units)

grey-brown silty mudstone with minor 1 to 5 cm vf grained sandstone to siltstone interbeds and gutter casts (up to 40 cm thick and 2 m across) filled with vf grained sandstone showing HCS; crosscutting vf grained sandstone dikes up to 2 cm thick

Key

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- fossil gastropod shells
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- root traces
- fossil bone
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- hummocky cross-stratification (HCS)
- gutter cast
- not exposed

Abbreviations

vf - very fine
f - fine
m - medium
c - coarse

base of section at UTM Zone 12, 517128E, 5439223N (NAD 83)

Appendix 4 – Biostratigraphic Sample from Measured Outcrop Section T2-R6W4-02

A sample was collected from the Foremost Formation in the lower part of measured outcrop section T2-R6W4-02 (southeastern Alberta) for biostratigraphic analysis (see Figure 4 for location). The sample was sent to G. Dolby & Associates Ltd. (Calgary) for palynological study. Details of sample preparation and analytical methodology are given in Dolby (2010). Results are detailed below.

Sample 5535 (2.9 m): grey-brown silty mudstone in measured outcrop section T2-R6W4-02 (Foremost Formation)

Age: Early Campanian
Environment: brackish; estuarine/lagoonal
Remarks: Spores and pollen dominate this assemblage but there are a modest number of dinocysts, mostly simple peridinioids that point to a restricted, brackish environment. Rare marine forms include *Trithyrodinium fragile, Palaeohystrichophora infusiorides, Heterosphaeridium difficile.* The latter has an international extinction point in the mid-Santonian but there have been Campanian records in northern Canada. However, it is not certain if these occurrences are due to reworking.
The angiosperm pollen flora is of Early Campanian age and is composed of *Aquilapollenites* spp., *A. turbidus, A. rigidus, A. trialatus, A.* cf. *clarireticulatus, Pulcherripollenites krempi, Proteacidites thalmanii,* pre-*Cranwellia* spp.
Spores such as *Laevigatosporites* spp., *Taxodiaceae* spp. and *Foraminisporis* spp. are numerous to very abundant. A significant freshwater influence is suggested by the presence of *Vesperopsis* sp. and numerous *Pediastrum* spp. (freshwater algae). A restricted brackish environment is indicated, possibly upper estuarine or lagoonal.

Appendix 5 – Outcrop Gamma-Ray Methodology

Gamma-ray values, in counts per second, were measured on the outcrop sections in southeastern Alberta at nominal measurement intervals of 0.5 m (section T2-R6W4-01) and 0.25 m (section T2-R6W4-02) using a hand-held GR-135 spectrometer. The counting time was 10 seconds and total counts were measured (above a lower threshold of 20 keV). Each measurement was obtained by placing the base of the front part of the GR-135 (near the detector) directly against the outcrop at the measurement location. Measurement locations were chosen to be as planar as possible over areas of approximately 0.5 m in diameter. If necessary, loose material was scraped away to expose outcrop before the gamma-ray data were collected.

GR-135 Specifications

Manufacturer: SAIC (Mississauga, Ontario)
Model: Exploranium® GR-135 Plus "The Identifier" (GR-135GEO, geophysical model)
Year of Manufacture: 2007
Version: 6V01.02
Detector: sodium-iodide (thallium) [NaI(Tl)] detector with a 65 cm^3 (4.0 cu in.) volume (38 mm in diameter and 57 mm in length)
Stabilization: external cesium (^{137}Cs) source (stabilization completed daily)
Mode: manual (search mode)
Count Rate Measurement: counts per second
Sample Time: 10 seconds
Scan Window: total (above lower threshold of 20 keV)
Averaging: off
Channels: 1024